

Highlights from EF09 - BSM

More general explorations

Tulika Bose, Zhen Liu, Simone Pagan Griso

https://snowmass21.org/energy/bsm_general

Aug.30-Sep.3, 2021



WISCONSIN
UNIVERSITY OF WISCONSIN-MADISON



Reminder: EF09 Focus Questions

representative,
not comprehensive.

- Are there **new interactions** or **new particles** around or above the electroweak scale? To what extent can future experiments probe this?
- **Long-lived** and **feebly-interacting** particles represent an alternative paradigm with respect to traditional BSM searches. To what extent can future detectors and accelerators probe such particles ?
- How do we conduct searches in a more **model-independent** way ?
- How do we **compare the results** of different experiments in a more model-independent way to **ensure complementarity** and avoid gap in coverage?
- Is **lepton flavor universality** violated ? What do we learn from high energy/ p_T searches ?

EF09 - BSM general exploration

To explore these questions, EF09 has been organizing activities around four areas

Heavy Bosons

- Explore new interactions
- Standard candles for EF machines (Z' , W' , q^* , ...)

New Fermions

- New matter content
- Heavy neutral leptons, Vector-like quarks, ...

Long-Lived Signatures

- Heavy vs Light new LL particles
- Interplay with detector design

Other exotica

- Inclusive BSM searches
- AI-powered anomaly detection method
- ...

Identify important benchmarks, explore new collider options, focus on the physics messages

Status and plans of EF09 activities

We received 73 LoI (+66 EoI) for snowmass projects

- That was quite some time ago..
- Some have already results, some progressed, some paused, new ones have started..

Recently launched a survey to gather information on projects you have been working on and plans

- Thanks for the prompt answers!
- We will highlight some of these contributions in the following slides
- If you haven't answered already: let us know filling [this quick form](#)

Parallel session w/ EF08 during this workshop

- Updates on selected representative studies
- Discussion on plans for benchmarks and main summary plots (more on this to come!)

Nr	LoI PDF file
1	AE/SNOWMASS21-AE7-EF9-003.pdf
2	CE/SNOWMASS21-CF5_Cf7-EF9_EF0-TF9_TF0_SGWB-102.pdf
3	CF/SNOWMASS21-CF7_CF5-EF2_EF9-TF9_TF0_Ashutosh_Kotwal-104.pdf
4	CompF/SNOWMASS21-CompF7_CompF3-EF9_EF0-114.pdf
5	EE/SNOWMASS21-EF10_EF9-042.pdf
6	EE/SNOWMASS21-EF10_EF9-069.pdf
7	EE/SNOWMASS21-EF10_EF9-071.pdf
8	EE/SNOWMASS21-EF10_EF9_Andreas_Albert-094.pdf
9	EE/SNOWMASS21-EF10_EF9_Filip_Zarniecki-054.pdf
10	EE/SNOWMASS21-EF10_EF9_Kulkarni_Suchita-149.pdf
11	EE/SNOWMASS21-EF10_EF9_Liu_Wang_Xie-085.pdf
12	EE/SNOWMASS21-EF10_EF9_diego_redigolo-104.pdf
13	EE/SNOWMASS21-EF2_EF9-CF5_CF0-TF9_TF0-211.pdf
14	EE/SNOWMASS21-EF2_EF9-RF6_RF0-TF7_TF8_Claudius_Krause-226.pdf
15	EE/SNOWMASS21-EF3_EF9-TF7_TF0_Doojin_Kim-045.pdf
16	EE/SNOWMASS21-EF4_EF9-139.pdf
17	EE/SNOWMASS21-EF5_EF9-210.pdf
18	EE/SNOWMASS21-EF6_EF9_Wright-157.pdf
19	EE/SNOWMASS21-EF8_EF9-229.pdf
20	EE/SNOWMASS21-EF8_EF9-RF6_RF0_Rebecca_Gonzalez_Suarez-147.pdf
21	EE/SNOWMASS21-EF8_EF9-TF7_TF0-AE4_AF0_Hannsjoerg_Weber-228.pdf
22	EE/SNOWMASS21-EF8_EF9-TF7_TF0_Doojin_Kim-062.pdf
23	EE/SNOWMASS21-EF8_EF9-TF7_TF8-269.pdf
24	EE/SNOWMASS21-EF8_EF9_Bansal-242.pdf
25	EE/SNOWMASS21-EF8_EF9_Mikael_Berggren-261.pdf
76	EE/SNOWMASS21-EF9-010.pdf

Organization

Resume bi-weekly meeting: Fri Sep 17th @ 12:00-1:30PM US Eastern Time

- Same frequency as before Snowmass pause (shifted time by 1 hour!)
- Critical for continuous feedback from/to the community:
 - provides forum to hear everyone's ideas (early-career members especially encouraged!)
 - ensures homogeneous results
 - help newcomers to get started
- Aim to dedicate each meeting to one area

Planning a BSM workshop (joint EF08/EF09/EF10) during the first months of 2022

- Identify remaining high-priority items
- Follows the useful workshops and x-group/frontier meetings we had
 - e.g. Dark Sector and LLP (w/ AF/RF), LFV (w/ RF), Dark showers (w/ EF10), ...
- More details will be available soon

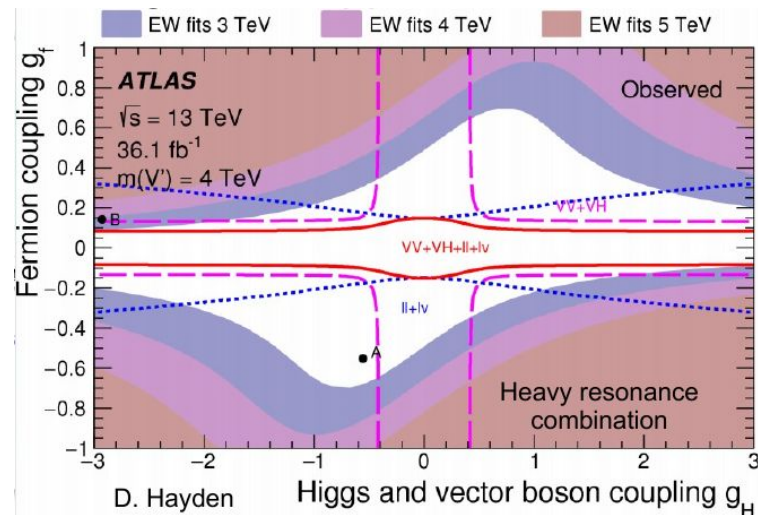
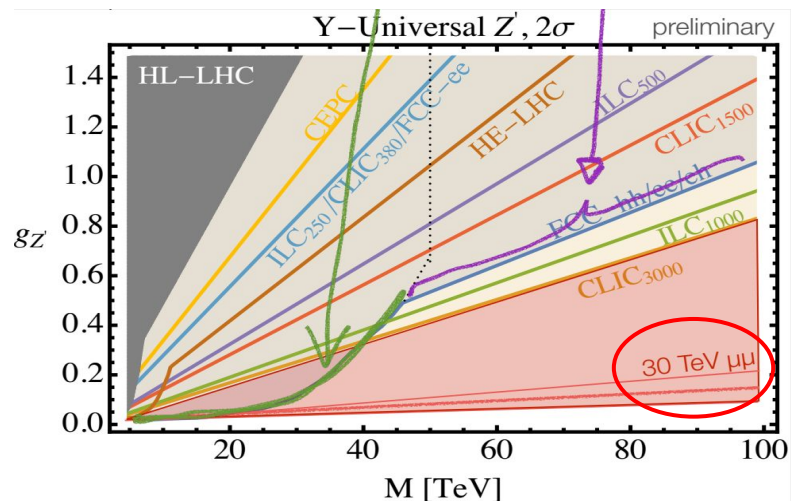
New Resonances

- Identifying Simplified models in representative final states as
 - Dilepton, Dijets, Diboson (VV, Vh, etc), ...

We hope to layout the basic reach of future collider programs **comprehensively** in these modes.

- Interplay with indirect searches
- Scan in energy/collider parameters
- Possibly explore more complicated modes (multi-bosons, boosted topologies, etc.)

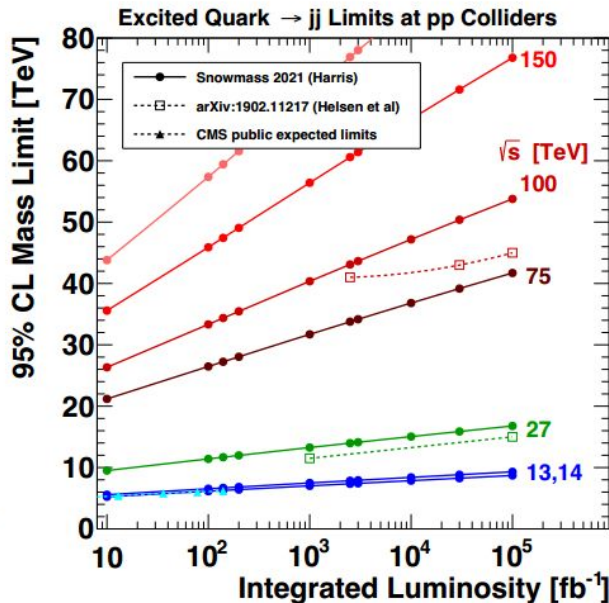
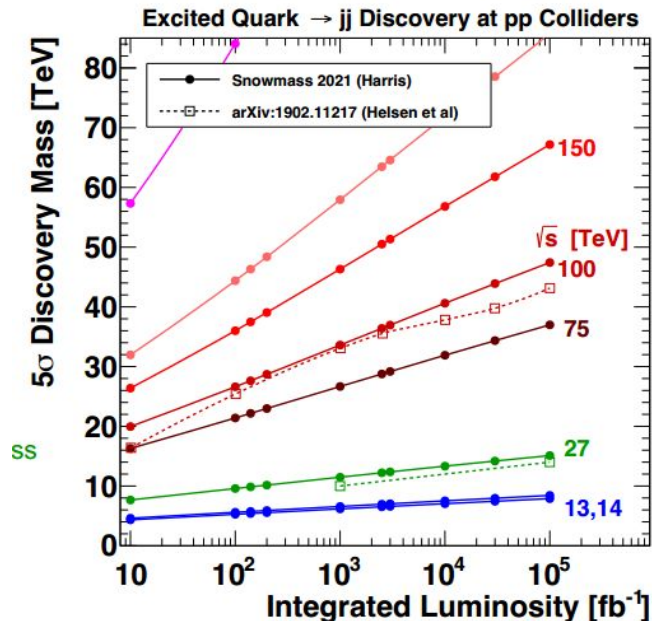
Add updates since European Strategy (e.g. muon collider results, new HL-LHC results etc.)



Sensitivity to Dijet Resonances at proton-proton Colliders

R. M. Harris with E. Gurpinar Guler & Y. Guler

- **Collision Energies:** 13, 14, 27, 75, 100, 150, 200 & 500 TeV
- **Luminosities:** $10 - 10^5 \text{ fb}^{-1}$ and machine benchmarks in between.
- **Models:** Excited Quarks (q^*), Diquarks, Colorons, W' , Z' , RS gravitons
- **Preliminary q^* results below**, working on other models & signal shape studies



q^* 5 sigma Discovery Mass

HL-LHC (14 TeV, 3 ab^{-1})
7 TeV

HE-LHC (27 TeV, 10 ab^{-1})
13 TeV

FCC-hh (100 TeV, 30 ab^{-1})
44 TeV

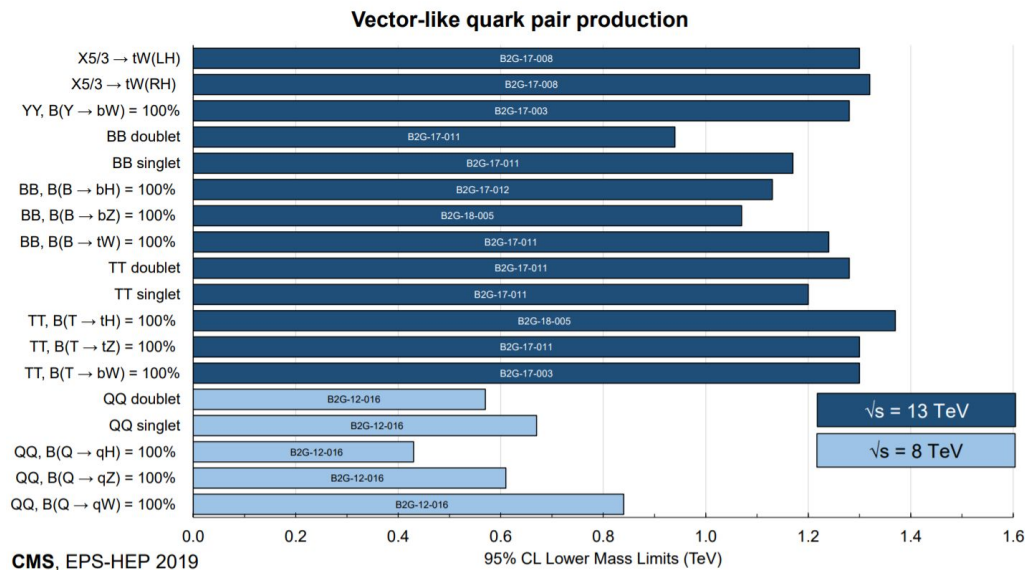
New fermions

Leaning towards selected simplified modes:

- Heavy Neutral Leptons
- Vector-like Quarks (T, B, X5/3)
- Leptoquarks, Top squark are covered through (EF08)

Already many new results, aim to identify gaps and call for contributions

- E.g. leptoquarks projections for muon collider (arxiv:2104.05720)



VLQ topologies not much studied for the European Strategy.
Opportunity to add new results, updates, summary plot (if possible)

Tools to search for pNGB and top-partners in composite Higgs models

A. Banerjee, D. Buarque Franzosi, G. Cacciapaglia, A. Cornell, L. Mason, A. Deandrea, G. Ferretti, T. Flacke, B. Fuks, L. Panizzi, W. Porod [LOI nr. 23]

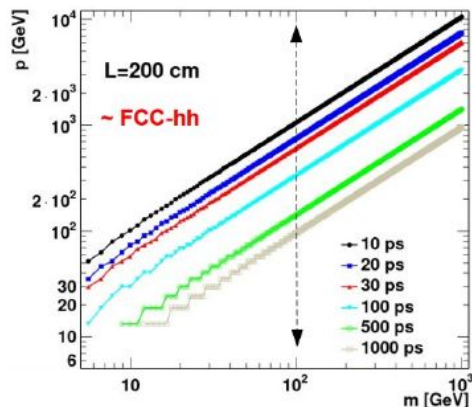
- **Goal:** Study exotic pseudo Nambu-Goldstone bosons and top-partners arising in gauge theory realizations of (partial) compositeness, integrating model building techniques and automated simulation tools to be applied at HL-LHC and FCC.
- **Physics targets:**
 1. Exotic **top partner decays** ($T/X \rightarrow t/b \phi$) can provide the most promising discovery channel in some regions of parameter space in contrast to the conventional channels ([1907.05929](#), [1908.07524](#), [2107.07426](#), [2107.12402](#))
 2. **Di-boson** decay of singly- and doubly-charged pNGB scalars leading to multi-leptons and multi-jets events potentially with sizable missing transverse energy.
 3. **BSM Z** and Higgs decays into pNGBs ($Z \rightarrow \gamma \phi$, $h \rightarrow Z \phi$, $h \rightarrow \phi \phi$) at a future e^+e^- collider, as a complementary probe with respect to hadron colliders.
- **Software development:** A new automated tool chain for compositeness studies
 1. Relying on FeynRules ([1310.1921](#)) and the Standard Model implementation shipped with the package.
 2. The user can in **one Mathematica command** add to the implementation any vector-like fermion (in the broken phase) and all the interaction terms allowed by $SU(3)_C \times U(1)_{EM}$.
 3. Generation of a UFO library for leading-order simulations with MG5_aMC ([1405.0301](#)).
 4. **Validated** against the existing model of [1610.04622](#) (that includes X, Y, T and B states).
 5. To-do: generalisation to add in a single command full $SU(2)$ multiplets, extension to NLO-QCD, addition of scalars, automated connection to a UV-complete setup, *etc.*

• *We invite interested experimentalists to join!*

x-group
impact!

Long-lived particles

- Strong community interest (~30 Lols received on the topic)
- LLP searches have strong interplay with detector design!
 - Of the uncovered (or less well-covered) signatures, which ones are most demanding in terms of new technologies or experiments needed?
 - how can we take advantage and/or shape future development in detector technology?
 - how to reasonably approach projection for detectors at early stage of design?



BSM particle with $M=100$ GeV can be identified up to momentum:

- 700 GeV in $|p|$ for $\sigma_{\text{TOF}}=20$ ps
- 70 GeV in $|p|$ for $\sigma_{\text{TOF}}=1$ ns

Can identify massive stable particles in very boosted regime!

Snowmass21 contributed
paper: [arXiv:2005.05221](https://arxiv.org/abs/2005.05221)

See also IF/EF session on collider requirements in previous [CPM meeting](#) and C. Vernieri's presentation on Monday

Long-lived particles

- How do we compare future collider options ?
 - “must-have” LLP signatures, synergy with other groups (EF02, EF08, EF10 in particular)
 - Compile a short list of benchmark models; harmonize across groups/frontiers
 - Varying assumptions of detector performance ?

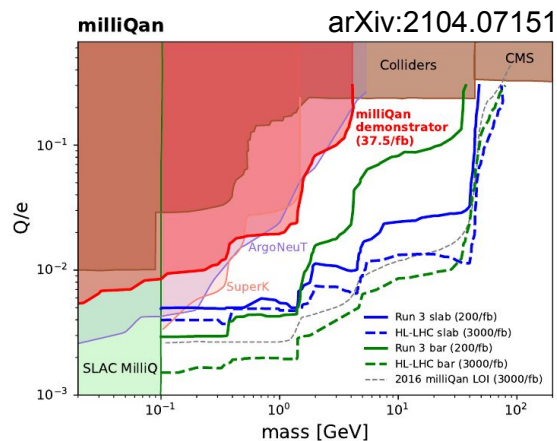
LLP: modes under consideration

- | | |
|--|---|
| <ul style="list-style-type: none">○ Colored LLP<ul style="list-style-type: none">■ (gluino, mini-split SUSY)■ (LSP mass 0 GeV and 100 GeV mass gap)■ (mass v.s. τ)○ Non-colored LLP<ul style="list-style-type: none">■ (Higgsino, GMSB)■ (decay via Higgs and Z, getting reach from both leptonic and hadronic decays)■ (mass v.s. τ) | <ul style="list-style-type: none">○ Higgs portal<ul style="list-style-type: none">■ (Higgs to LLPs, neutral naturalness)■ (LLP mass 50 GeV, 10 GeV, 1 GeV)■ (Br v.s. τ)○ Disappearing Track<ul style="list-style-type: none">■ (Higgsino reach and Wino reach)■ (mass reach at different colliders)○ Other more complicated scenarios:<ul style="list-style-type: none">■ Dark showers w/ EF10■ Light LLP benchmarks w/ RF6 |
|--|---|

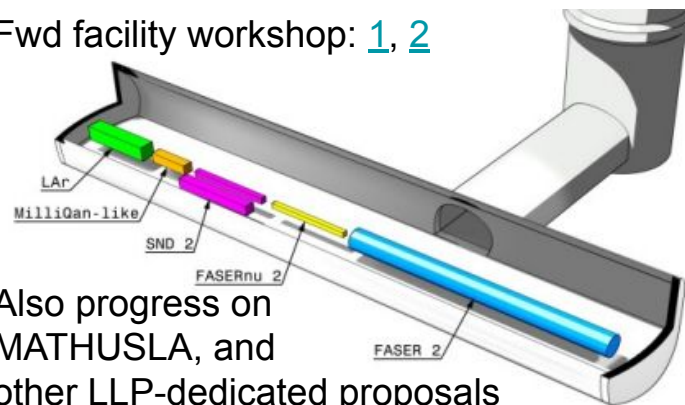
See EF08/EF09
parallel session!

Long-lived particles

- How do we achieve comprehensive coverage with existing accelerator facilities ?
 - Build benchmarks on and extend the LLP white paper: arXiv 1903.04497
 - Better exploit upgraded HL-LHC detectors, advanced techniques, new trigger strategies...
 - Exploit the full potential of auxiliary experiments (FASER, milliQan, MATHUSLA, MOEDAL,...)
 - Growing interest and efforts on dark showers phenomenology and projections



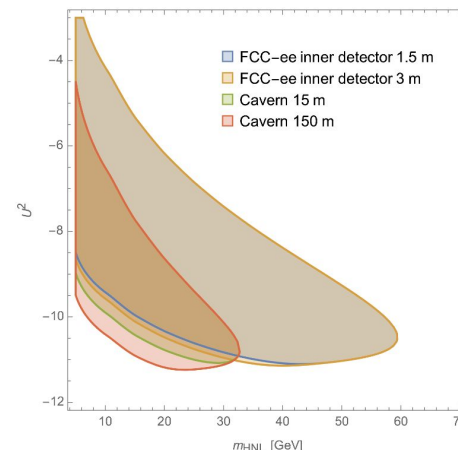
Fwd facility workshop: [1](#), [2](#)



Also progress on
MATHUSLA, and
other LLP-dedicated proposals

Searches for Long-Lived Particles at the FCC-ee

- LLP searches are an attractive alternative (and complement) to mainstream new physics searches, but challenge conventional reconstruction and trigger methods.
- At the FCC-ee ([arXiv:2106.15459](#))
 - Three main lines to explore: Heavy Neutral Leptons, Hidden sectors (ALPs), exotic Higgs decays
 - Experimental opportunities: Detector design, Reconstruction algorithms, Trigger
- Work was kickstarted within the FCC-ee the [Snowmass Lol](#), now a case study (<http://cern.ch/go/QT86>)
 - Regular meetings: <https://indico.cern.ch/category/5664/>, mailing list: LLP-FCCee-informal@cern.ch
 - Master thesis: Towards Vertexing Studies of Heavy Neutral Leptons with the Future Circular Collider at CERN [link](#)
 - Latest papers on the topic presented in the group
 - Z-Boson Decays into Majorana or Dirac (Heavy) Neutrinos ([arXiv:2105.06576](#))
 - Tera-Zooming in on light (composite) axion-like particles ([arXiv:2104.11064](#))
 - HECATE: A long lived particle detector concept for the FCC-ee or CEPC ([arXiv:2011.01005](#))

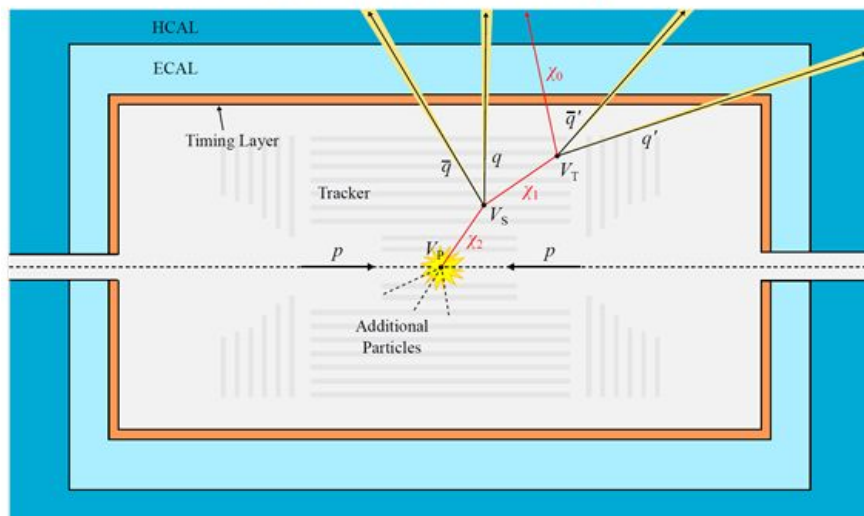


Tumblers: A Novel Collider Signature for Long-Lived Particles

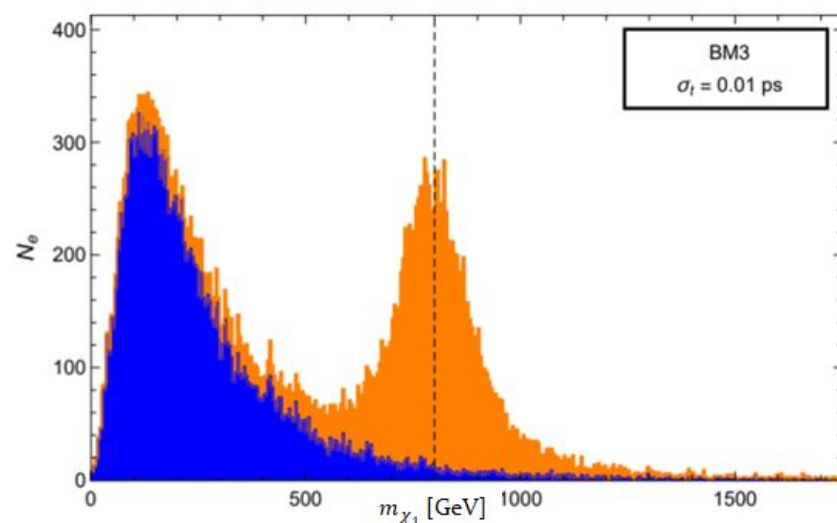
[Keith Dienes, Doojin Kim, Tara Leininger, Brooks Thomas, 2108.02204]

Main idea: We point out a novel signature of physics beyond the Standard Model which could potentially be observed both at the Large Hadron Collider (LHC) and at future colliders. This signature, which emerges naturally within many proposed extensions of the Standard Model, results from the multiple displaced vertices associated with the successive decays of unstable, long-lived particles along the same decay chain. We call such a sequence of displaced vertices a “tumbler”. As a novel collider signature, tumblers will provide an interesting channel in the search for long-lived particles with the aid of dedicated timing layers installed in the LHC detectors during the HL-LHC upgrade.

An example tumbler signal



An example distribution of reco. mass

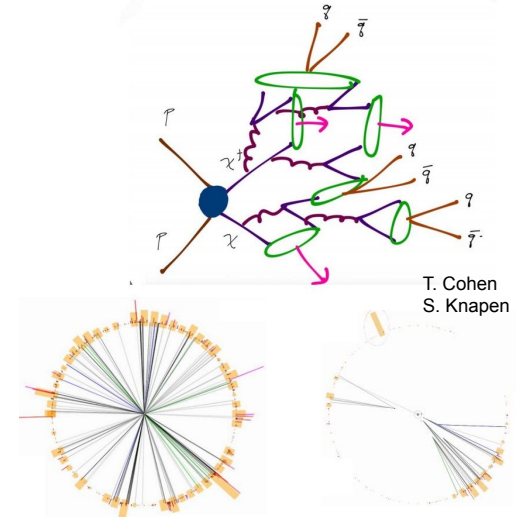
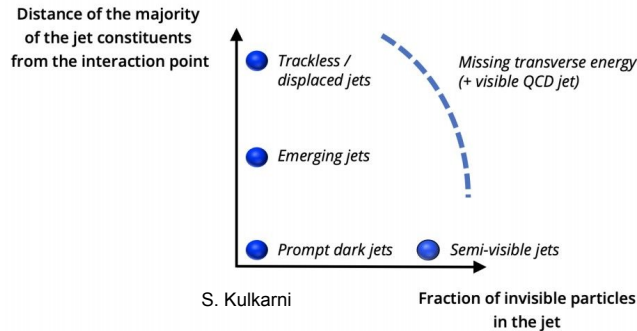
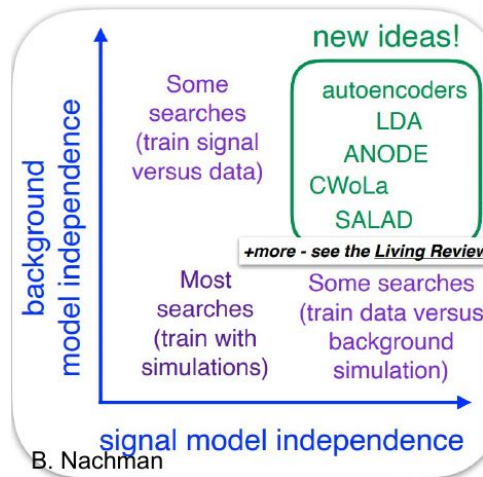


Other Exotica

Think ahead to ensure we don't miss unexpected new physics!

- New techniques are being developed (heavily using ML tools)
- Are there accelerator/detector/readout requirements that can facilitate searching for “unexpected” phenomena?

Strongly Coupled



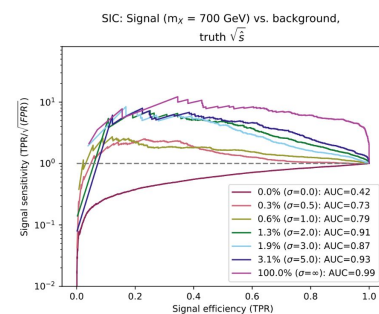
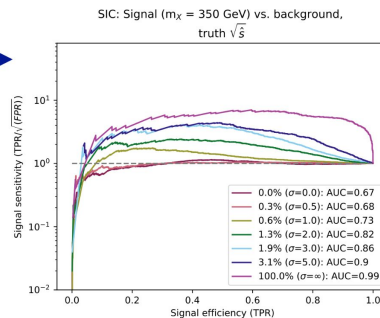
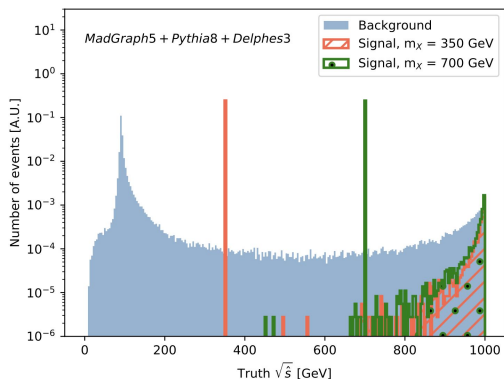
High-dimensional Anomaly Detection with Radiative Return in e+e- Collisions

Julia Gonski, Jerry Lai, Benjamin Nachman, Inês Ochoa

- **Goal:** understand potential of existing anomaly detection methods on e+e- datasets
 - Focus on radiative return events to scan collision \sqrt{s} for new hadronically decaying resonances ($e^+e^- \rightarrow X \rightarrow aa \rightarrow JJ$)
- **Dataset:** 1 TeV CoM e+e- with ILCgen Delphes card (conclusions are not detector/accelerator specific)
- Train over high-dimensional Particle Flow Networks in both data vs. simulation (supervised) and data-driven signal region vs. sideband (weakly supervised) configurations
- **Results:** can enhance $\sim 1\sigma$ significant signal excesses ($m_X = 350$ GeV and 700 GeV) by a factor of 2-3x
- Consider different ways of measuring collision energy (eg. with or without ISR photon) to inform future detector resolution and acceptance

arXiv:2108.13451

⇒ Paper drafted, on the arXiv soon!



Track-Based Triggers for Exotic Signatures

Karri Folan DiPetrillo, Jessica Far, Chris Guo, Tova Holmes, Jessica Nelson, Katherine Pachal
EF9-IF4-008

Motivation: HL-LHC track-triggers offer an opportunity to improve trigger efficiency for a wide range of exotic models with long-lived particles and unconventional track signatures.

Method: Study truth-level signal efficiency as a function of a hypothetical track-trigger's baseline parameters.

Goal: Identify which baseline track-trigger parameters allow for maximum sensitivity across a range of representative signatures. Identify possible improvements for planned ATLAS/CMS upgrades.

Signatures considered

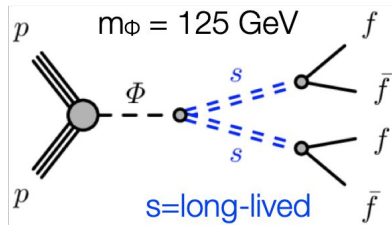
- High multiplicity of soft, prompt particles
- Displaced jets
- Displaced leptons
- Heavy meta-stable charged particles

Track-trigger parameters

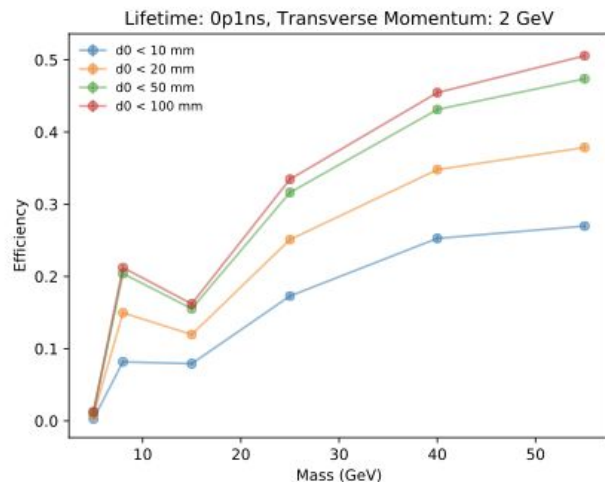
- minimum track p_T
- maximum track d_0
- number of tracker layers & radii

Studies nearly completed!
write-up by ~end Sep

Preview of results for displaced jets



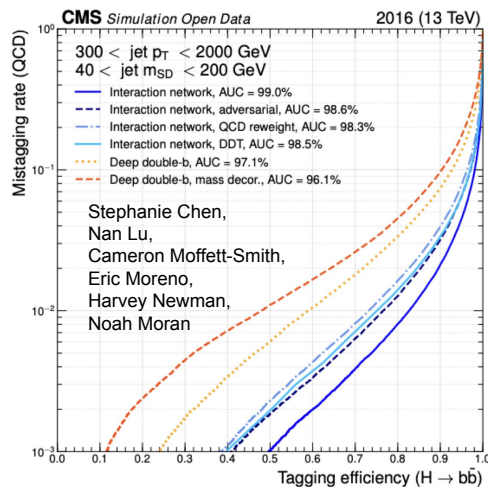
Impact of extending maximum impact parameter on a long-lived higgs-portal model, as a function of LLP mass for $c\tau = 0.1$ ns



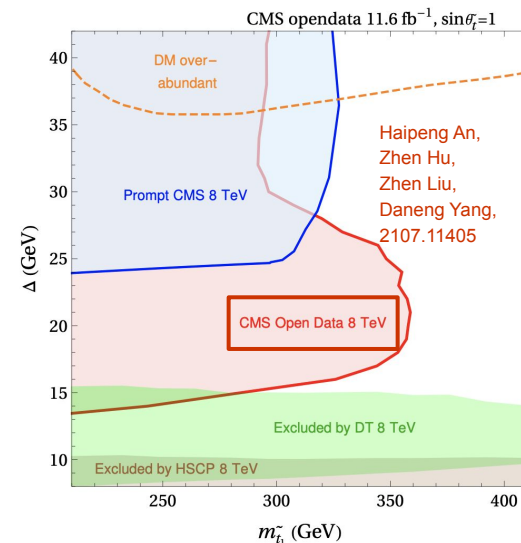
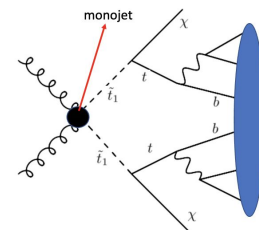
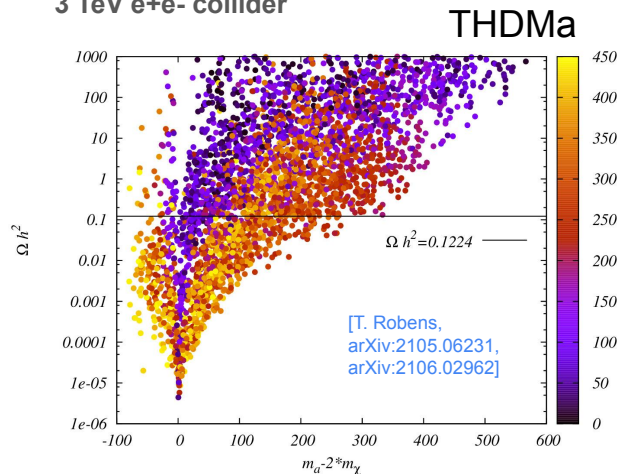
And much more!

Di-Higgs resonances (w/ EF02) for
HL-LHC and future hadron colliders

- Include taus
- Advanced background rejection techniques



Relic density as a function of mediator
mass m_a and DM mass m_{χ}
Dominant production cross sections at a
3 TeV e+e- collider



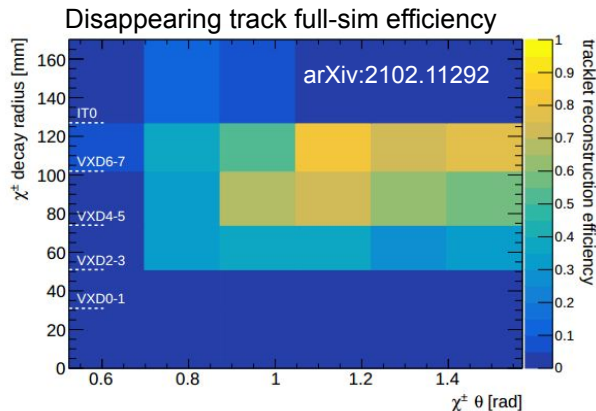
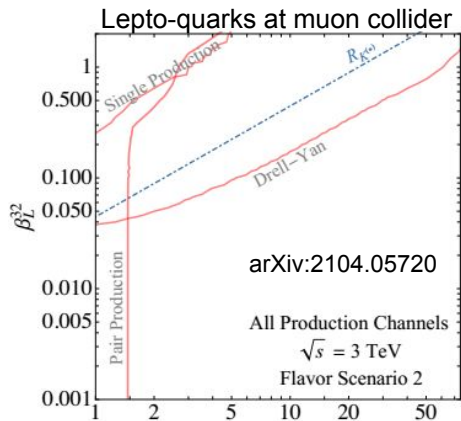
Other options for future colliders

A large interest of the community for physics at muon colliders (~ 20 papers since snowmass “pause”)

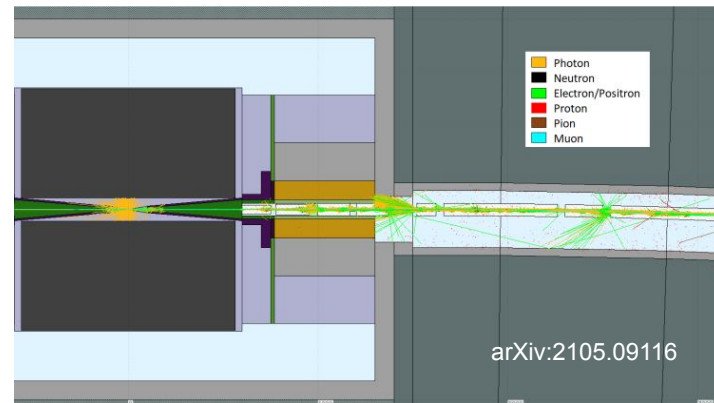
- Important to combine pheno studies and “full simulation” to prove beam-induced backgrounds can be kept under control; synergy with IF/AF

Multi-TeV energy e^+e^- and $\gamma\gamma$ colliders also a very interesting option

- Can't aim for a comprehensive coverage, but very important to have key projections on selected benchmarks to show their potential (contact us!)



Beam-induced bkg characterization at muon collider



EF09 Highlights, Conclusions

Four key areas: heavy bosons, new fermions, long-lived particles, other exotica

A variety of new results have been developed since the snowmass start

Aim to increase focus on in-depth discussions on key summary plots and looking for volunteers to take on making those plots and providing inputs

- Varying energy, probing new collider options, interplay with detectors are crucial new ingredients that provide valuable insights!
- Still many activities in need of new contributions, great occasion especially for early-career

Re-starting bi-weekly meetings Fridays @ 12:00-1:30PM US Eastern Time

- BSM workshop (joint EF08/EF09/EF10) coming up in early 2022!

Backup

LFV

- Large interplay with dedicated flavor experiments
 - ▶ Weak indirect constraints from $\tau \rightarrow \mu\gamma$ and $\tau \rightarrow e\gamma$.
 - ▶ But $\mu \rightarrow e\gamma$ strongly constrains $\text{BR}(H \rightarrow \mu e)$ and $\text{BR}(H \rightarrow \tau\mu) \times \text{BR}(H \rightarrow \tau e)$
 - ▶ Severe indirect constraints on $Z \rightarrow \mu e$ from $\mu \rightarrow e\gamma$, $\mu \rightarrow 3e$, $\mu \rightarrow e$ conversion (barring accidental cancellations).
 - ▶ Complementary sensitivity in the case of taus.
- LFV in top decays access new physics at $\sim \text{TeV}$ scale at LHC
- Only few projection studies available \rightarrow hope to expand in Snowmass
 - Also interest in projection of new particles LFV decays (e.g. $W_R \rightarrow 3l, 2ljj$)

Probing the energy scale for new physics

